To study the conductivity of flame, it is convenient to use a row of small Bunsen flames placed so that they touch each other. I use a row of fifty flames burning from quartz tubes 1 cm. apart. This gives a flame 50 cm. long and about 10 cm. high. The quartz tubes insulate very well, so that a current can be passed along the flame horizontally from one end to the other.

When two parallel platinum electrodes immersed in the flame are connected to a galvanometer and battery, it is found that a measurable current is obtained. The relation between the current (i) and the difference of potential (V) between the electrodes is given by the equation

$$V = Ai^2 + Bdi,$$

where A and B are constants, and d denotes the distance between the electrodes. If d is small, say one or two millimetres, the term Bdi is negligible (except when i is very small), and we get $V = Ai^2$. In this case the current is almost independent of the distance between the electrodes.

The reason for this peculiar relation between the current and potential difference becomes apparent when the variation of the potential along the flame from one electrode to the other is examined. An electrometer is connected to two platinum wires, which are immersed in the flame, and can be moved along horizontally between the electrodes. Each wire takes up the potential of the flame at the point where the wire is situated, so the deflection of the electrometer indicates the difference of potential between the two points where the wires are put in. Suppose one wire is allowed to touch the positive electrode and the other is gradually moved along the flame from the positive to the negative electrode. It is found that in the space between the electrodes there is a small uniform potential gradient, but near each electrode there is a comparatively sudden drop in the potential. The drop near the negative electrode is much larger than the drop near the positive electrode. Thus nearly all the electromotive force of the battery is used up close to the negative electrode. This shows that nearly all the resistance offered by the flame to the passage of the current is close to the negative electrode. The positive ions in the flame move towards the negative electrode and the negative ions towards the positive electrode; in fact, the current is carried through the flame by these two streams of ions. Hence, close to the negative electrode, the current must be carried entirely by positive ions moving towards it, and at the positive electrode the current must be entirely carried by negative ions. We find that the resistance near the negative electrode is much greater than near the positive electrode, so that we conclude that the negative ions carry the current more easily than the positive ions. With a given electric force, the negative ions move very much faster than the positive ions. It has been shown experimentally that the velocity of the negative ions is about 10,000 cm. per sec. for one volt per cm., while that of the positive ions is about 100 times smaller than this.

In the flame away from the electrodes the electric force is found to be proportional to the current, so that here the flame obeys Ohm's law like a metallic conductor. Its conductivity is about 10^{11} times less than that of copper. In the equation $V = Ai^2 + Bdi$, the term Bdi is the part of the E.M.F. used up between the electrodes, so it is proportional to the current and to the distance. Sir J. J. Thomson has shown theoretically that the drop of potential near the electrodes should be proportional to the square of the current, as is found experimentally to be the case.

The conductivity of a Bunsen flame may be compared with the conductivity of liquids, such as water. In pure water some of the molecules are dissociated into ions and the water is a conductor, although only a poor one; but if a salt like sodium chloride is dissolved in the water, the salt dissociates into ions almost completely, and the conductivity is greatly increased. Suppose we hold a bead of salt on a platinum wire in a flame, then the salt volatilises and the flame is filled with its vapour, and, just as with the water, the conductivity is enormously increased.

With the long flame and an electrode at each end, we can try the effect on the current of putting salt in different parts of the flame between the electrodes. In this way it is easy to show that the current is practically unchanged, unless the salt vapour is put in close to the negative electrode, but in that case it produces a very great increase in the current. This confirms the conclusion that nearly all the resistance to the passage of the current is situated close to the negative electrode. When the salt is put in anywhere it diminishes the resistance there to a small fraction of its value, but it is only close to the negative electrode that the diminution in the total resistance is appreciable. If we measure the potential difference between two points in the flame away from the electrodes, and then put salt vapour in the flame between them, we find that the P.D. drops to a small fraction of its value, although the current is the same as before. This shows clearly that the salt vapour greatly increases the conductivity wherever it is put in.

When some salt is put on the negative electrode, the sudden drop in potential there almost disappears, and we get a nearly uniform potential gradient from one electrode to the other, so that now the resistance is nearly uniformly distributed along the flame. If now salt vapour be put in anywhere between the electrodes, the current is increased. If, for example, we fill half the length of the flame with salt vapour, we nearly double the current.

When salt is put on one electrode, the flame can be used as a rectifier for an alternating current, for when the salted electrode is negative the resistance of the flame is much smaller than when it is positive.

Measurements have been made of the conductivities of a number of alkali salt vapours in a current of air flowing along a platinum tube heated in a gas furnace. An electrode was fixed along the axis of the tube, and the current from it through the salt vapour to the surrounding tube was measured with a galvanometer. It was found that at temperatures above 1400° C., and with electromotive forces of about 1000 volts, the current was proportional to the amount of salt passing through the tube, and for different salts in equal quantities inversely proportional to the electrochemical equivalent of the salt. This shows that the quantity of electricity per molecule of salt is the same for all salts. It was also found that the quantity of electricity carried per molecule was equal to that carried per molecule when a solution of salt in water is electrolysed. It appears, therefore, that the laws of electrolysis discovered by Faraday for liquids apply also to salts in the state of vapour.

When a molecule of salt like sodium chloride dissociates into two ions in water, the sodium atom forms the positive ion and the chlorine atom the negative ion, and when a current is passed through the solution the sodium is attracted to the negative electrode and the chlorine goes to the positive electrode. We might expect the same thing to happen when a current is passed through the salt vapour in a flame. If we put two wires in the flame, and put some sodium salt on one, and then connect them to an induction coil, and pass a discharge from the salted one to the other, we find that the yellow sodium vapour appears at it when it is the negative pole, but not when it is positive. This shows that in the flame the positive ions of the salt vapour contain the metal just as they do in solutions. The negative ions, however, do not appear to be the same in flames as in solutions. In flames the very high velocity of the negative ions indicates that they are the electrons the properties of which have been investigated in vacuum tubes by Sir William Crookes and Sir Joseph Thomson. The positive ion, then, is an atom or molecule, while the negative ion is an electron the mass of which is several thousand times smaller. This is the explanation of the fact that the negative ions move 100 times more quickly than the positive ions.

HEAT-TRANSMISSION IN STEAM BOILERS.[1]

AT the present time the relations between the various factors that govern the flow of heat from a gaseous fluid into a metal surface with which it is in contact remain extremely obscure.

The formulæ in general use, which express in a concrete manner the views of engineers upon the subject, are of a purely empirical character and without theoretical

[1] Abstract of paper on "Laws of Heat and Transmission deduced from Experiment," by Prof. J. T. Nicolson, read before the Junior Institution of Engineers.

foundation. They all agree in attributing to the greater or smaller temperature-differences between gas and wall which occur in practice the higher or lower rates of heat transference which are met with, and in ignoring any effect upon that rate which may be produced by a variation of the speed of gas flow.

In 1874 Prof. Osborne Reynolds brought before the Literary and Philosophical Society of Manchester a paper entitled "The Extent and Action of the Heating Surface of Steam Boilers." In this paper, starting with the laws then recently discovered of the internal diffusion of fluids, he endeavoured to deduce from theoretical considerations the laws for the transmission of heat. His formula expressing this law is

$$H=(A+B\rho u)(T-\theta),$$

where A and B are constants, ρ, u, and T are the density, speed and temperature of the fluid, and θ is the temperature of the wall. For small values of u this becomes Newton's law of cooling; for large values the A-term is less important, and the formula becomes one which is applicable to steam boilers.

No further investigation of the subject was made until 1897, when Dr. T. E. Stanton made a series of experiments to test the truth of the views advanced. He found that the amount of heat transferred when *water* forms both the heat-conveying and heat-receiving medium is nearly proportional to the speed of flow, and that Osborne Reynolds's views were abundantly confirmed.

In 1899 Prof. Perry, in his book on the "Steam Engine," wrote a chapter on "How Fluids give up Heat and Momentum"; and, in discussing the efficiency of steam boilers, he finally remarked:—"It seems to me that when a good scrubbing action is established on both sides of the metal there ought to be at least ten times, and may be more than 100 times, as rapid an evaporation per square foot of heating surface as has yet been obtained in any boiler."

There is no record that up to the present time any British or Continental engineer has paid serious attention to these pregnant words, or has realised the immense possibilities which lie behind Prof. Osborne Reynolds's statements, should their truth be experimentally demonstrated.

The author attached so much importance to the matter that, in 1898, after reading Dr. Stanton's paper, he constructed an apparatus in his laboratory at the McGill University for the purpose of further study. His removal to Manchester in 1899, and his subsequent occupation by other work, had, however, prevented his further taking up the question until 1905.

Since that time three series of experiments have been made by himself, and one series by his pupil, Mr. H. P. Jordan, on the subject.

The apparatus used was usually of a fairly simple type, consisting of two long concentric tubes through which (*a*) warm compressed air and cold water, (*b*) superheated steam and cold compressed air, (*c*) superheated steam and cold water, and (*d*) products of combustion of coal and boiling water, were passed in opposite directions through the two pipes at various rates of speed.

An analysis of all these results, together with those of Petiet and Geoffroy, and Henry and Marié upon locomotive boilers, have led to the formula:—

$$Q=\left[\frac{\phi}{200}+\frac{\sqrt{\phi}}{40}\left(1+\frac{1}{m_1}\right)\rho_1 u_1\right]\left(T-\theta\right)$$

for the heat flow Q in B.Th.U. per sq. ft. per hour when:

T = temperature of gas (°F.),
θ = ,, wall (°F.),
ρ_1 = density of gas (lbs./cu. ft.),
u_1 = speed of gas flow (feet/sec.),
$\phi = \frac{1}{2}(T+\theta)$ = mean film-temperature,
m_1 = hydraulic mean depth of gas-flue (inches).

According to this formula, the rate of heat transfer *for a given temperature-difference* between gas and wall depends upon (*a*) the mass-flow of the gas, lb. per sec. per sq. ft. of flue-section; (*b*) the average temperature of gas and wall; and (*c*) the smallness of bore of the tube or width of channel conveying the gas.

The usual rate of heat transfer in steam boilers is (from 3 to 10) about 5 B.Th.U. per sq. ft. per hour per degree difference of gas and water (*i.e.* wall) temperature. In the author's experimental apparatus he succeeded in transmitting more than 300 B.Th.U. per sq. ft. per hour per degree difference, *although the air was only about* 30° F. *hotter* than the water.

In an experimental boiler he was able also to produce evaporations at the rate of from 30 lb. to 50 lb. of steam (as from and at 212° F.) per sq. ft. of *indirect* heating surface per hour when the gas temperature was at about 1500° F. and the water at 300° F. In both cases this high rate of heat transference was principally due to the very high gas velocities employed. These varied from 300 to 550 feet per second, whereas in ordinary boiler practice it never exceeds 150, and is usually from 10 to 30 feet per second.

The way in which the new experimental facts should influence practice in steam generation may be stated as follows:—

In the first place, since the amount of heat that can be transmitted for a given temperature difference is almost directly proportional to the speed of the gases, a reduction of area of the heating surface in steam boilers—to one-half, one-quarter, or even one-tenth of what is now usual—can be made without the chimney temperatures being raised or the efficiency lowered to any material extent. Or, otherwise, if the surface be kept the same, but the cross-sectional area through the flues be reduced, in order to obtain the necessary high gas speed, a very much lower chimney temperature and correspondingly higher efficiency can be secured than is now available.

Accordingly, drafts of 10 or 20 inches of water gauge, induced by fans, should always be employed for really economical working.

In the case of boilers of usual construction, in which the gases pass through flues or tubes and leave the boiler at a point where the temperature on the other side of the heating surface is that corresponding to the steam pressure, a limit will soon be reached as to the amount of draft-suction which can be employed, and this from one or other of two causes:—

(*a*) Whilst the fire need not be forced, even when these high drafts are used, to a greater extent than that now usual, the high speed of entry of the glowing gas at the furnace end of the tubes will cause leakage, and some other construction for such purposes than that now generally employed must be sought for.

(*b*) The fall in temperature of the chimney gases due to the small flue-section and accompanying high speed will, as intimated above, certainly provide an additional amount of evaporation which can be drawn upon to cover the extra power required for the fans, but the margin between present chimney temperatures and the lowest which are possible in ordinary designs of boiler under the above conditions is not very great when the steam temperatures are from 350° F. to 400° F. A limit will therefore soon be reached beyond which it will not pay to pass. The author, after a careful investigation of costs and running expenses, has good reason to believe that this limit of draft-pressure is, even for the ordinary type of boiler, much higher than that now in common use.

In the second place, since the author's experiments have shown that with a counter-current flow of gas and water it is possible to lower the gas temperature (at such high speeds as he used) to within 20° F. of that of the entering feed, we have here the evidence that chimney temperatures of 100° F. to 150° F. can be reached and maintained provided only high gas and water speeds are resorted to and the boiler is designed on the economiser principle, with strict attention to counter-current methods of flow.

Now such a low chimney temperature as this corresponds to a transmission efficiency of more than 95 per cent.! The margin of additional evaporation available for the supply of the fan-power is, accordingly, so much greater than is required that not only can higher economies be obtained on this system than have hitherto been thought possible, but they can be effected with boilers having smaller areas of heating surface, smaller total volumes, smaller floor areas, lighter weights, and lower first costs than those we ordinarily employ.

Finally, since the enhanced evaporative efficiency of the

heating surface due to high speed, and its correspondingly reduced area, renders it possible economically to line that part of the surface nearest to the furnace with refractory material, and so to secure a non-water-cooled or reverberatory chamber in which the combustion processes may be perfectly completed, any special need for skilful firing is dispensed with, and, by providing plenty of air and an ample mixing space behind the bridge, excellent results, and an entire absence of smoke, may be obtained without special care.

Such brick-lined combustion chambers cannot now be afforded next the furnace in ordinary boilers, for the heating surface at this point is almost all that the boiler has of even *moderately* good evaporative power, and it cannot be sacrificed, as convective heating surface, to be lined with a protective coating for the purposes of a combustion chamber.

Nor is this all. Any lack of high furnace temperature accompanying such air excess can so easily be made up for by the additional gas speed that nearly the whole heat-value of the coal can still be passed into the water, even when the flue gases are relatively cool, without any undue extension of the heating surface being found necessary. We see also that the extra quantities of air just mentioned may be admitted to the furnace without encountering the evil results which usually follow such a course. For, as practically all the heat is extracted from the gaseous products before they reach the chimney when this high-speed counter-current method of working is adopted, it matters but little to what extent they are diluted.

Thus the proposed new method of working, using both high-speed and counter-current gas and water flow, appears to be capable of introducing several features of radical improvement into the present practice of steam-boiler construction and working.

The author believes that some such features must shortly be incorporated in boiler design if the steam engine is to retain the preeminence it has so long enjoyed in the economical production of power.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

AMONG the courses of lectures announced by the University of Göttingen in the Bulletin of the American Mathematical Society, we notice the entry:—" By Prof. L. Prandtl: Theory of aëronautics, four hours."

Science announces that the passage of the Legislative Appropriation Bill carrying 196,400*l.* for the University of Kansas, gives the University all it asked, except an appropriation for a dormitory. From the same source we learn that by the will of Ellen A. Kendall, her residuary estate is given to Wellesley College to found a professorship bearing her name. It is provided that if the fund exceeds 12,000*l.* the income of the excess shall be used to aid worthy students.

THE *Lancet* states that one friend of McGill University has recently promised to give 20,000*l.* to the University as soon as 100,000*l.* has been raised elsewhere, and another has presented the governors of the institution with an unconditional gift of 5000*l.* The above announcements were made at a recent meeting of the corporation of the University, and as the authorities have now in hand about 20,000*l.*, it was decided for the present to leave in abeyance the plans for obtaining the 400,000*l.* which the institution needs, and to concentrate all possible efforts towards securing the other 80,000*l.* necessary before the new 20,000*l.* donation can be accepted.

WE have received a copy of the March issue of *The Record*, the magazine of the South-Western Polytechnic Institute, Chelsea. In addition to the interesting chronicle of the doings of the various societies in connection with the institute, the magazine contains several articles by old students and others on aspects of the engineering profession. An illustrated account is given of a recently acquired 50-ton testing machine in the mechanical engineering laboratory, and a compound steam engine provided by the London County Council is included. These additions are good instances of the satisfactory equipment with which technical institutions of London are now able to instruct their students in the practical requirements of industrial enterprise.

THE annual meeting of the Swanley Horticultural College (for Women) was held on March 24. The chairman, Sir John Cockburn, in moving the adoption of the report and balance-sheet, laid stress on the admirable work done by the college in meeting the two great requirements of the day, viz. rural education and the higher education of women. Mr. C. Bathurst, in seconding the resolution, directed attention to the growing demand on the part of local educational authorities for teachers qualified to give instruction in nature-study and school gardening in both elementary and secondary schools, and the increasing usefulness of Swanley in meeting this demand. Short courses of instruction upon gardening and other country occupations will be given at the college from May 6 to June 15 and from June 18 to July 27. There will also be a nature-study course from July 31 to August 14.

As technical education in India is about to receive serious consideration, attention is directed in an article in *Indian Engineering* for February 20 to certain causes of failure in the past. The original scheme of education in India seems to have been instituted for the principal purpose of providing a supply of Indian clerks having a knowledge of English. As the result of fifty years of this policy it is now found that higher education is pursued with too exclusive a view to entering Government service, and its scope is thus unduly limited. Again, difficult work requires expert workers, and it is to be hoped that these will be forthcoming, and that they will have a freer hand in dealing with technical education problems than has hitherto been the case in the Indian educational administration. Steps should be taken to secure that expert educationists will be in a majority, and that their reports will not require to be made through alien departments. The example of Japan shows what is possible in Eastern countries, but Japan was initially guided by men of educational experience and scientific knowledge.

THE issue of the *Oxford and Cambridge Review* for the Lent term provides a varied table of contents. In an article on some defects in the curriculum of the public schools and a suggested remedy, Mr. A. R. Gidney directs attention to certain resolutions adopted at last year's conference of headmasters, and the decision to appoint a committee to consider a scheme of studies for boys from the ages of nine to sixteen or thereabout. Against the present scheme of studies, says Mr. Gidney, three indictments may be brought:—it is surcharged with languages; it recognises inadequately the bent of individual boys; and it fails to arouse an intellectual interest in the majority of boys. Having dealt with the congested state of the present curriculum, the writer wisely insists that a selection of subjects must be made, and that in making it it must be remembered that the majority of boys have a greater ability for one class of studies than another, and that this ability, though innate, does not manifest itself usually with any clearness until a particular epoch in the boy's life. Most authorities will agree with these conclusions, but many will consider that Mr. Gidney gives too little prominence to the need for practical studies of several kinds in the scheme of education he outlines. Mr. Leonard Hill, F.R.S., contributes an article on oxygen for athletes, and after explaining and summarising some of the researches of Dr. John Haldane, Dr. Pembrey, Prof. Zuntz, Mr. Flack, himself, and other workers in connection with the inhalation of oxygen, he concludes his essay by remarking that he is "indifferent whether oxygen is used by athletes or not; if they choose to try they will soon find out whether the advantage gained is worth the trouble and expense." Mr. Hill "is content with the knowledge he has gained, that oxygen inhalation combined with exercise is a potent method of treatment in various pathological states." Mr. M. M. Pattison Muir writes on the abuse of the word "scientific."